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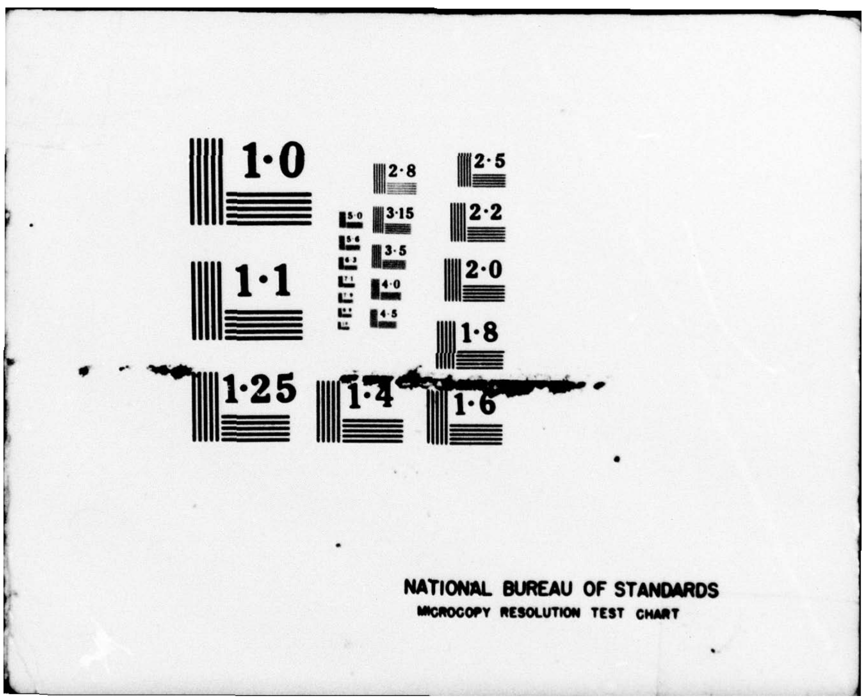
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CONTROL AND SUPPRESSION OF SWIRLING AND SECONDARY FLOWS IN CONFINED STREAMS

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FINAL REPORT

BY
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AND
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JUNE 1, 1974 TO JULY 15, 1977

U.S. ARMY RESEARCH OFFICE

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19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Wind-Tunnels Design; Duct Flows; Confined Streams; Swirling Flow; Swirl Generation; Swirl Control; Swirl Management; Swirl Reduction Ratio; Fluid Rotation; Vorticity Measurement; Streamwise Vorticity; Vane-Vorticity Indicator; Test Flow Conditions; Tangential Jets;

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The main objectives are not only to develop recommended procedures for control of large scale swirling and secondary flows, but also to extract from empirical observations general concepts which design and test engineers could adapt for "tailoring and manipulating" their own special flows with different rotational characteristics. Several typical rotational flows were generated and superimposed on the flow through the test section. Careful calibration was carried out using hot-wire anemometers, and miniature

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19. KEY WORDS - continued

Airfoils Trailing Vortex; Wing Tip Vortex; Flow Manipulator; Pressure-Drop Coefficient; Large Scale Vorticity; Vorticity Suppression; Wind-Tunnels Modification; Helicopters-Testing in Wind Tunnels

20. ABSTRACT - continued

vane-vorticity indicators. These flows represent the basic target conditions to be controlled by inserting various flow manipulators: honeycombs, screens and perforated plates. Comparison of the characteristics of the flow downstream of the manipulators (e.g., distribution of streamwise vorticity) to the original test flows provides a measure of the efficacy of the manipulators in suppressing large scale vorticity as well as clues to dominant mechanisms of the flow transformations.

I. Summary of Research Findings

A fluid mechanical problem which invariably faces design and test engineers is the need to generate flows with controlled characteristics for the testing of engines, aircraft and helicopter models, turbines and pumps, special instruments and components, etc. When the tested models are helicopters, the swirl and downwash from the rotor generate large scale rotational nonuniformities which subside very slowly around the tunnel circuit and could well contaminate the free stream conditions either directly or through intermittent separation phenomena. Open throat and open return tunnels generally have problems with secondary flows and swirls due to the effects of the surroundings of the tunnel. The research under this grant dealt with the understanding of principles and with the application of various techniques for "manipulating" the mean flow and the unsteady flow characteristics in wind tunnels, channels and ducts, primarily where swirling and secondary flows are concerned.

Several rotational flows were generated [2]*. These "test flows" have greatly different rotational characteristics, i.e. different distributions of angular momentum across the test section, in order to represent a wide range of typical swirling flows.

Since the rotating component of velocity is of great importance in these flows, various ways to measure either the tangential velocity or the streamwise vorticity were investigated [2]. One particularly useful tool for measuring the streamwise vorticity is the vane vorticity indicator [4]. Utilizing advanced signal processing techniques, these miniature vanes provide

* Numbers in brackets refer to the List of Manuscripts

direct and rapid evaluation of the streamwise vorticity, even in turbulent flows with high intensities. However, the vanes must be properly calibrated using flows with known rotational characteristics, as explained in our AIAA paper [4]. Without these calibration curves, or outside their range of application, the vanes can only be used to give an indication of the vorticity in the flow.

Using the vane-vorticity indicator along with various arrays of hot-wire anemometers, careful documentation of the test flows was carried out [2,3&5]. These flows represented the basic target conditions to be controlled by inserting various flow manipulators: honeycombs, parallel plates (or turning vanes), screens, perforated plates, etc. Comparison of the flow characteristics downstream of the manipulators to the original "test flows" provided a measure of the effectiveness of the manipulators as well as clues to the dominant mechanisms.

The effect of many parameters, such as mesh size in relation to the swirl size, free stream turbulence level, pressure drop, etc. on the operation of some standard flow manipulators can be summarized [5] as follows:

a) The effectiveness of a manipulator is reduced as the strength of the impinging swirl increases, for the same size vortex and the same free-stream velocity.

b) The reduction in swirl improves as the size of the swirl increases, for the same strength, as long as the dominant mechanism for reducing the swirl stays the same.

c) Increasing the free-stream turbulence level or its scale leads to more lateral diffusion of the swirl downstream of the manipulator. This enhances the operation of manipulators which do not generate much turbulence or significantly alter the shape and size of the swirling flow, as in the case of a screen. On the other hand, it disrupts the operation of manipulators which generate large amounts of turbulence, such as honeycombs [1] and perforated plates [7]. These manipulators operate with the aid of the mechanism which breaks the swirl into several parts that recombine downstream of the manipulator.

d) The pressure drop across the manipulator plays a minor or indirect role in the control of swirling flows.

e) For manipulators of the same mesh size, the effectiveness decreases as the solidity increases.

One important finding deals with the ability of achieving the same reduction in swirl with two different manipulators under comparable flow conditions. This permits the selection of the "best" manipulator based on other criteria, such as pressure drop coefficient or favorable turbulence control, which are usually desirable parameters to optimize.

These conclusions also outline some important considerations, notably that a manipulator should be scaled to the swirl size so that the mesh is not too large (which would allow all of the swirling part of the flow to go through one cell), nor too small (this would break the swirl up into too many small parts resulting in inefficient operation). The experiments indicate that a mesh of approximately 20-25% the width of a concentrated swirl will give the best performance.

The results for honeycombs were unexpected due to the presence of two separate mechanisms. All of the honeycombs that were used removed all of the swirl in each flow condition, although through different mechanisms. Long honeycombs, which are typical of those traditionally used in wind tunnels, eliminate all of the swirl completely within the honeycomb and are examples of "overkill", i.e., inefficient use of turbulence manipulators with resulting loss in overall performance. This approach is not very efficient due to the high pressure drop coefficient of these manipulators. The much more efficient mechanism of removing the swirl by effective recombination of several large weakened swirls downstream of the manipulators is present when using larger mesh honeycombs of short length (less than 4 mesh lengths).

These honeycombs have a much lower pressure drop coefficient and are much shorter and of larger mesh size than those previously thought necessary for application to this type of problem.

While certain of these very short length, large mesh honeycombs are most efficient in removing swirl, the total picture is not that simple. Perforated plates, screens and grids can be extremely useful in situations where turbulence control is a problem, where many scales of swirling flow exist, or where other basic swirl reduction mechanisms, such as shear at the wall of the duct, are present. The large mesh honeycombs generate high levels of nonuniform turbulence [3], and with many sizes of swirl present, swirl reduction would not be as effective due to the competing mechanisms within the same manipulator. In addition, other mechanisms may hinder the effectiveness of its basic mechanism, such as in presence of rapid lateral diffusion caused by increased background turbulence.

Since recent studies of the control of free stream turbulence [1,7] show that rotational nonuniformities hinder the reduction of the turbulence, it is more efficient to work on the swirl first and then the turbulence. Screens and perforated plates can take advantage of higher background turbulence for more effective swirl reduction, so that use of either of these in combination with a large mesh honeycomb would be more efficient than using a longer, smaller mesh honeycomb.

The above information provides many recommendations to the design and test engineer for manipulation of flows in wind tunnels and ducts. However, to get further details regarding the mechanisms and turbulence behavior, more work was done on using hot-wire arrays in complex three dimensional turbulent flows. The yaw sensitivity of hot-wires, which is required for x-wire measurements, was investigated and a further generalization of the cosine law was developed. The results [8] show that it reduces the errors in the mean velocity measurements for typical probes by at least a factor of three. The relation also leads to a significant correction to the Reynolds stress and the bi-normal turbulence intensity measured with x-probes. The effect of various parameters, such as Reynolds number or length to diameter ratio, on the yaw sensitivity of hot wires was also determined experimentally with the aid of the present yaw relation. The new relation is better than all previous relations in reducing errors due to changes in these parameters. The results also suggest that the mean yaw sensitivity of all probes should be obtained in presence of some background turbulence with spectral content similar to that of the flow under consideration. In addition, the temperature sensitivity of hot-wires, which can lead to significant errors in velocity measurements obtained in non-isothermal flows (e.g., the mixing of streams of unequal temperatures as in the tangential-jets swirl generator), was investigated and a technique was developed [9] to compensate for such temperature changes.

II. Scientific Personnel

Hassan M. Nagib	Associate Professor
John L. Way	Associate Professor
Roald A. Wigeland	Research Assistant, Ph.D. degree candidate, expected May, 1978
Masoom Ahmed	Research Assistant, M.S. degree earned May, 1976
Robert E. Drubka	Research Assistant, M.S. degree earned May, 1977
Annick Fraissinet	Research Assistant, B.S. degree earned June, 1977

III. List of Manuscripts

1. Loehrke, R. I. and Nagib, H. M., "Control of Free Stream Turbulence by Means of Honeycombs: A Balance Between Suppression and Generation," ASME Paper 76-FE-2; J. Fluids Eng., Trans. ASME, Vol. 98, No. 3, 1976.
2. Ahmed, M., Wigeland, R. A. and Nagib, H. M., "Generation and Management of Swirling Flows in Confined Streams," I.I.T. Fluids and Heat Transfer Report R76-2; Interim Technical Report, ARO-ITR-76-1, 1976.
3. Ahmed, M., Wigeland, R. A. and Nagib, H. M., "Generation, Measurement and Suppression of Large Scale Vorticity in Internal Flows," Proceedings of the SQUID Workshop on Turbulence in Internal Flows, Washington, D.C., 1976, Hemisphere Publishing Corp., 1977.
4. Wigeland, R. A., Ahmed, M. and Nagib, H. M., "Vorticity Measurements Using Calibrated Vane-Vorticity Indicators and Comparison with X-Wire Data," AIAA Paper No. 77-720, AIAA 10th Fluid and Plasma Dynamics Conference, Albuquerque, New Mexico, June, 1977.
5. Wigeland, R. A., Ahmed M. and Nagib, H. M., "Management of Swirling Flows with Application to Wind-Tunnel Design and V/STOL Testing," AIAA Paper No. 77-585, AIAA/NASA Ames V/STOL Conference, Moffett Field, California, June, 1977.
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7. Tan-atichat, J., Nagib, H. M. and Loehrke, R. I., "Interaction of Free Stream Turbulence with Screens and Perforated Plates: A Balance Between Turbulence Scales," submitted to Journal of Fluids Engineering, Trans. ASME.

8. Drubka, R. E., Nagib, H. M. and Tan-atichat, J., "On Temperature and Yaw Dependence of Hot-Wires," I.I.T. Fluids and Heat Transfer Report R77-1; Interim Technical Report, ARO-ITR-77-1, 1977.

9. Drubka, R. E., Tan-atichat, J. and Nagib, H. M., "Analysis of Temperature Compensating Circuits for Hot-Wires and Hot-Films," I.I.T. Fluids and Heat Transfer Report R77-2; Interim Technical Report, ARO-ITR-77-2, 1977, appears also in DISA Information, No. 22, p. 5, 1977.

IV. List of Presentations

1) NASA Ames Research Center, Moffett Field, California, October, 1975. Presented "Control and Suppression of Swirling and Secondary Flows in Confined Streams," at Chief Investigators Conference on "Helicopter and V/STOL Aircraft Research."

2) University of Illinois at Urbana-Champaign, Urbana, Illinois, October, 1975. Presented one of the seminars in the University Fluid Mechanics Series, "On Management of Turbulence by Passive Manipulators and Aero-acoustic Coupling Phenomena."

3) New Orleans, Louisiana, March 1976. Presented "Control of Free Stream Turbulence by Means of Honeycombs: A Balance Between Suppression and Generation," at the 18th Annual Fluids Engineering Conference.

4) Illinois Institute of Technology, Chicago, Illinois, April, 1976. Presented a department seminar on "Generation and Management of Swirling Flows in Confined Streams."

5) Washington, D.C., June 1976. Presented "Generation, Measurement and Suppression of Large Scale Vorticity in Internal Flows," at the SQUID Workshop on Turbulence in Internal Flows.

6) Eugene, Oregon, November 1976. Presented "Measurements in Swirling Flows Using Various Vorticity Indicators," at the 29th Fluid Dynamics Meeting of the American Physical Society.

7) University of California, San Diego, California, January, 1977. Presented a seminar on "Management of Free Stream Turbulence: A Balance Between Scales."

8) Illinois Institute of Technology, Chicago, Illinois, May, 1977. Presented a department seminar on "On Temperature and Yaw Dependence of Hot-Wires."

9) NASA Ames Research Center, Moffett Field, California June, 1977. Presented "Management of Swirling Flows with Application to Wind Tunnel Design and V/STOL Testing," at the AIAA/NASA Ames V/STOL Conference.

10) Albuquerque, New Mexico, June 1977. Presented "Vorticity Measurements Using Calibrated Vane-Vorticity Indicators and Comparison with X-Wire Data," at the AIAA 10th Fluids and Plasma Dynamics Conference.